TITLE

Relationships between highly-skilled golfers' clubhead velocity and vertical ground reaction force asymmetry during vertical jumps and an isometric mid-thigh pull

BRIEF RUNNING HEADER

Relationships between asymmetries and golfers' clubhead velocity

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ABSTRACT

Clubhead velocity (CHV) is a commonly measured variable within golf due to strong associations with increased drive distance. Previous research has revealed significant relationships between CHV and vertical ground reaction force (vGRF) variables during bilateral tasks including a countermovement jump (CMJ), squat jump (SJ), drop jump (DJ) and isometric mid-thigh pull (IMTP). Asymmetries have been linked to performance outcomes in a number of sports, however few studies have assessed asymmetries within golf. The current study, therefore, examined the relationships between CHV and vGRF asymmetries for CMJ positive impulse, SJ positive impulse, DJ positive impulse and IMTP peak force (PF). Furthermore, the level of agreement for asymmetries between protocols were assessed via Kappa coefficients. Fifty highly skilled (handicap ≤5) male golfers attended laboratory and range-based testing sessions. Positive impulse and PF were measured using a dual force platform system, with CHV measured using a TrackMan 3e launch monitor. There was no significant relationship (r = -0.14 to 0.22) between CHV and each of the vGRF asymmetry measures. Of the golfers tested, 26 had a 'real' asymmetry in the CMJ, 18 had a 'real' asymmetry in the SJ, 25 had a 'real' asymmetry in the DJ and 27 had a 'real' asymmetry in the IMTP. Kappa coefficients indicated that asymmetries rarely favoured the same limb (k = 0.06 to 0.39) with asymmetries varying for individual golfers between protocols. As such, asymmetries are nether beneficial or detrimental to CHV, but are inherently individual and dependent on the task.

<u>Key words</u>

Golf, strength and conditioning, asymmetries, impulse, peak force.

INTRODUCTION

The ability to drive a golf ball over greater distances is an important component linked to success within the game of golf. Evidence has suggested that PGA Tour golfers who hit a golf ball 20-yards further, achieved an advantage of 0.75 strokes per round (9). Indeed, further research indicated that increased drive distance is linked to significantly lower scores on Par-4 and Par-5 holes (22). Within the golf literature, clubhead velocity (CHV) is a commonly reported kinematic variable, since this accounts for 75% of the variance in ball velocity, which, inherently leads to greater drive distance (38). Whilst drive distance is an important outcome measure within golf, extraneous variables such as environmental conditions (24) and centredness of strike (6) affect the reliability of the data. Given that CHV is unaffected by these confounding variables, it offers a robust assessment of golfers' performance.

The downswing of highly skilled golfers is initiated from the ground-up, with energy transferred from the ground through the kinetic chain to the clubhead (31). Due to this important interaction between the ground and the golfer, a number of studies have sought to determine the mechanisms associated with performance enhancement within the game of golf. Specifically, field-based investigations have highlighted significant relationships between CHV and vertical jump peak power ($r = 0.61$, $p < 0.01$) (21), ($r = 0.54$, $p < 0.01$) (36), jump height ($r = 0.47$, $p < 0.01$) (21), ($r = 0.44$, $p < 0.05$) (36), and repetition maximum strength during a back squat ($r = 0.54$, $p < 0.01$) (21), ($r = 0.81$, $p < 0.05$) (34). Whilst these relationships advocate the use of field-based protocols, without laboratory equipment, such as force plates, these protocols are unable to ascertain more in-depth performance strategies such as vertical ground reaction forces (vGRF). Recent research, using force plates, has highlighted significant relationships between CHV and bilateral tasks such as isometric mid-thigh pull (IMTP) peak force (PF) ($r = 0.482$, $p < 0.01$), along with positive impulse during a countermovement jump (CMJ) ($r = 0.788$, $p < 0.001$), squat jump (SJ) ($r = 0.692$, $p < 0.001$) and drop jump (DJ) ($r = 0.561$, $p < 0.01$) (46). Whilst these bilateral assessments are a useful testing battery to profile golfers, they also provide an opportunity to assess possible links between CHV and vGRF asymmetries.

Asymmetry has been an area of research receiving considerable attention in recent years, due to the perceived link asymmetries have with both injury likelihood and decreased performance. Inter-limb asymmetries have been defined as the force of contraction of two limbs being unequal (26). Research has highlighted associations between asymmetries in strength and a reduction in both kicking accuracy (19) and power output during cycling (35). In addition, Bailey et al. (2) observed significant negative correlations between IMTP PF and jump height during both a CMJ ($r = -0.47$, $p < 0.01$) and SJ ($r = -0.52$, $p < 0.01$). Whilst there appears to be a general inclination for asymmetries in strength to be associated with reduced performance, research assessing asymmetries during jumping have found mixed results. Lockie et al. (29) reported no significant relationships between asymmetry scores during jumping and change of direction (COD) speed and sprint performance. Indeed, Hoffman et al. (23) observed no significant relationship between asymmetry and time to perform an 'L-run' task. Conversely, Maloney et al. (30) indicated that slower athletes in a COD task exhibited greater DJ height asymmetry than faster athletes. Additionally, Bishop et al. (7) observed a significant relationship between single leg CMJ asymmetry and slower sprint times in elite youth female soccer players.

Asymmetries have been suggested to be individual for different athletes (8), and may be a functional by-product based on adaptations due to the demands of the task (43). Indeed, research has indicated that more experienced Australian Rules football players had greater muscle cross-sectional area and presented greater asymmetries between kicking and support limbs due to task dependent adaptions (20). Further still, greater asymmetries within abdominal muscle morphology were shown to be associated with reduced low back pain in cricket fast bowlers (17). These studies highlighted the positive associations between asymmetries and athlete's performance within different sports. Given the conflicting findings asymmetries have with performance, further research is required to substantiate these links within other sports such as golf.

Golfers are required to conduct repetitive movements and will play between 6-10 hours each day, hitting up to 300 balls in a practice session (39). During the golf swing, peak vGRF can reach 1.09- and 0.98-times body weight on the left and right leg respectively (32). As Hart et al. (20) eluded to, side-to-side asymmetries are likely due to task adaptations, which may result in functional asymmetries being observed within golfers. There is limited research that has sought to investigate the prevalence of asymmetries within golfers and the relationships these asymmetries have with performance. Of the existing literature, research within golf has quantified asymmetries for torso rotation (1), hip morphology between the right and left leg (11) and isometric side bridge endurance (13). While these studies have highlighted that asymmetries are prevalent within golfers, these studies failed to quantify the relationships these asymmetries had with performance measures such as CHV. Wells et al. (45) utilised a vertical jump and reach test to measure the relationships dominant and non-dominant legs had with golfers' ball speed and drive distance. While there were differences in jump height between dominant (26.4 ± 8.5 cm) and non-dominant (25.3 ± 8.8 cm) legs, the authors were only concerned with the relationship between the magnitude of the vertical jumps as opposed to the relationships between jump asymmetries and golf performance. In addition, whilst the vertical jump and reach test provides a useful field-based procedure, it is limited in extractable biomechanical data such as impulse and PF.

To date, no study has attempted to assess the relationships between golfers' CHV and asymmetries during strength and jumping based tasks. Consequently, the aims of this study were 1) to provide an asymmetry profile for highly skilled golfers across a battery of strength and vertical jump tests and, 2) assess the associations between vGRF asymmetry and CHV. It is hypothesized that there will be a significant negative relationship between golfers' CHV and vGRF asymmetry within each protocol.

METHOD

Experimental Approach to the Problem

A cross-sectional correlation study using highly skilled golfers was conducted to assess the relationships between CHV and vGRF asymmetry. To assess vGRF asymmetries, a CMJ, SJ, DJ and IMTP were employed since these have been extensively used within previous research. Golfers' CHV was identified as the dependent variable with CMJ positive impulse, SJ positive impulse, DJ positive impulse and IMTP PF employed as independent variables since previous research has found strong correlations between CHV and these test variables (46). Each protocol was conducted by the same experimenter in order to ensure standardised procedures and assessment. Clubhead velocity assessment and laboratory analysis was conducted on separate days utilising a counterbalanced design.

Subjects

Fifty right-handed male category-1 (handicap ≤5) golfers (age: 20 ± 1.8 years, height: 1.81 ± 0.05 m, mass: 75.5 ± 12.1 kg, handicap: 2.9 ± 1.9) were recruited to participate in this investigation. A priori power analysis (G*Power, Version 3.1.9.2, University of Dusseldorf, Germany) determined that to achieve a statistical power >0.8, a medium effects size (0.35) and alpha level of 0.05 a total of 49 subjects were required. All subjects were experienced golfers, engaged in an average of 10.5 hours golf practice per week and had limited experience of resistance training. Subjects were injury free, completed a physical activity readiness questionnaire (PAR-Q), attended a familiarisation session and refrained from exercise 48 hours prior to all testing. Ethical approval was granted by the University's Ethics Board. Subjects were informed of the benefits and risks of the investigation prior to providing written informed consent.

Procedures

Anthropometric data (height and mass) were recorded following the completion of the PAR-Q and informed consent. As a warm-up, subjects cycled on an ergometer (Monark Ergomedic 874E, Cranlea Human Performance Ltd, UK) for 5 minutes at a cadence of 50 rpm with a resistance that yielded an intensity of 90-100 watts. Following this, a series of dynamic stretches were performed including clock lunges, overhead squats, gluteal bridges, scapula wall slides, thoracic rotations, internal and external hip rotations and vertical and horizontal arm swings which was supervised by the experimenter. Each subject received five minutes rest before completing testing of the SJ, followed by the CMJ, DJ and lastly the IMTP. Each protocol was performed bilaterally on dual Kistler force platforms (Kistler 9281, Kistler Instruments, Winterthur, Switzerland) sampling at 2000 Hz and captured using BioWare software. All data was smoothed with a low pass 4th order Butterworth filter as described by Winter (47). Residual analysis was used to determine optimal cut-off frequency (47) which was set at 30 Hz for the IMTP and 100 Hz for all three jump variations (25). Average force over a one second weighing phase established baseline measurements, with the instant of movement initiation determined based on a 10 N vGRF threshold shift from baseline as utilised by Tirosh and Sparrow (41). All of the data was analysed using Microsoft Excel™. Analysis into 5 subjects' data showed smoothing had a negligible effect when compared to raw data for CMJ positive impulse (smoothed = 257.48 N·s, raw = 257.48 N·s), SJ positive impulse (smoothed = 177.89 N·s, raw = 177.90 N·s), DJ positive impulse (smoothed = 414.44 N·s, raw = 414.44 N·s) and IMTP PF (smoothed = 1338.30 N, raw = 1340.52 N).

All subjects were taken through a standardised verbal explanation and practical demonstration by the investigator. Following this, subjects performed three practice trials prior to completing the test procedures. Each vertical jump was then performed three times with the feet hip width apart, hands placed on the hips, and with the instruction to jump as high and as fast as possible on the command '3, 2, 1, jump'. Each jump was interspersed with a two-minute recovery period.

Squat Jumps

During practice jumps, subjects set their preferential start position with knee (mean = 94 ± 11°) and hip angles (mean = 83 ± 15°) recorded using a manual goniometer. An adjustable bench was individually set to each subject's preferred squat depth to provide a standardised start position. Force plates were zeroed with the subjects set motionless in their lowered position of the squat. The subjects held their self-selected squat depth for five seconds then performed a concentric only bilateral SJ on the command '3, 2, 1, jump'. All force-time data was analysed on a computer screen, with a negative vGRF >50 N from the force trace deemed as a prior countermovement (40). If a countermovement was performed the data was discarded and the jump was performed again following the allocated rest intervals. Positive impulse (force x time) was calculated from the initiation of the propulsion phase (using a 10 N threshold) up until the time where force returns to zero, which is the point where peak positive (upward) velocity of the centre of mass is reached.

Countermovement jumps

Force platforms were zeroed with the subjects standing motionless in their start position. Bilateral countermovement jumps started with the subjects standing upright before lowering themselves into a self-selected squat depth and immediately jumping as high and as fast as possible on the command '3, 2, 1, jump'. Positive impulse was calculated from the area underneath the force-time curve. This was calculated from the point where force returns to bodyweight (using a 10 N threshold), which is the timepoint when peak negative (downward) velocity of the centre of mass is reached, up until the point that force returns back to zero and peak positive (upward) velocity of the centre of mass is reached.

Drop jumps

A 20 cm high box was set back from the force platforms. On the command ‘3, 2, 1, jump’ subjects ‘dropped’ from the box into a bilateral hip width stance and attempted to jump as high as possible whilst minimising their ground contact time. The experimenter discarded jumps adopting poor technique such as ‘stepping down’ or ‘jumping’ off the box. Jumps with ground contact time >250 ms were also discarded (46). After completing all the vertical jumps, the athletes rested for five minutes prior to taking part in the IMTP, which follows previous procedures reported by Leary et al. (28). Positive impulse was calculated from the vertical force trace including impulse pertaining body mass and force generated through muscular actions. This was calculated from the point that the force-time curve first rose above 10 N, which represented the first point of landing, up to when force returned to zero.

Isometric mid-thigh pull

All isometric testing was performed using a Smith machine (Pro-R, Pullum Sports, Luton, UK), which was set over the dual Kistler force platform system. Prior to data collection, subjects performed three sub-maximal bilateral isometric mid-thigh pulls, progressively increasing their pulling intensity from 50%, 75%, and finally 90% of their maximum. Subjects were positioned into their second-pull position of the clean, since this has been shown to correspond to the portion of the clean that generates the highest force output (16). From this position knee (mean = 146 ± 4°) and hip (mean = 153 ± 5°) angles were recorded with a manual goniometer. Subjects’ hands were attached to the bar with lifting straps to enable maximal effort, with the bar fixed in position. Once the IMTP position had been set, the subjects took 'slack' out of the bar and remained motionless whilst the force platforms were zeroed. Subjects were informed to pull the bar as hard and as fast as possible (18). Each pull was initiated after a countdown of '3, 2, 1 pull' with maximal isometric effort applied for five seconds as recommended by Haff et al. (18). Following each maximal pull, Subjects sat on a chair, but remained strapped to the bar. This was to maintain a constant hand position between pulls. A total of three pulls were performed with three minutes recovery time between each. Peak force during the IMTP was established from the maximal vGRF on the force-time curve subtracted by the lowest starting force. For each of the protocols, the average vGRF taken from the three trials were taken forward for analysis.

Clubhead velocity

Clubhead velocity was measured using a TrackMan 3e launch monitor (Interactive Sports Games, Denmark), as used by Oliver et al. (33). The TrackMan 3e launch monitor measures the linear CHV from the geometric centre of the clubhead at the instantaneous moment prior to impact (42), with research showing a median difference of -0.49 m/s (lower and upper interquartile range 0.85 – 0 m/s) with an 87% chance of always being within 1.12 m/s of the gold standard measure (27). Clubhead velocity was measured in a private driving range bay at the Belfry Golf Centre. The TrackMan was set-up based on the manufacturer's guidelines with the investigator specifying the intended target line. The warm-up followed the same procedures used as the laboratory testing. Subjects also hit a self-selected number of shots (7 ± 2 shots) with a 6-iron whilst gradually increasing their CHV. This was then followed with a self-selected number of shots (7 ± 2 shots) struck with a driver. Subjects used their own custom fit 6-iron and driver which comprised either a stiff or X-stiff shaft to ensure shaft flexibility didn't confound CHV data. Prior to data collection the investigator instructed each subject to ensure they struck the ball with maximum effort, whilst maintaining their normal swing mechanics and a centred strike on the clubface. The final two warm-up shots were instructed to be struck with maximum effort to ensure subjects were suitably prepared. Subjects' self-selected and struck 10 new range balls, aiming at the target and hit off an artificial turf mat and a self-selected tee height. Centeredness of strike was determined by sound, feel and the ball flight, with the investigator checking verbally with the subject after each shot. Any shots that fell outside this remit were discarded and additional shots were performed, up to a maximum of 15 shots.

Asymmetry calculations

A modified version of the symmetry index (37) was used to measure the vGRF asymmetry for the CMJ, SJ, DJ and IMTP. This modification defined the data as 'right leg' and 'left leg' rather than 'higher value' and 'lower value'. Therefore, the following equation was used to calculate asymmetry:

$$\text{Asymmetry} = ([\text{Right leg} - \text{Left leg}] / \text{Total} \times 100) \times \text{IF}(\text{Right} < \text{left}, 1, -1)$$

Given that the above equation could produce both positive (right leg) and negative (left leg) values, the 'IF function' in Microsoft Excel™ was employed to convert these to a positive value for statistical analysis. For example, if 25 golfers had a 10% asymmetry favouring the right leg and the other 25 golfers had a 10% asymmetry favouring the left leg, the mean asymmetry would be 10% (as all golfers present a 10% asymmetry).

Clubhead velocity analysis

The TrackMan 3e launch monitor provided real-time data on each of the subjects CHV for the ten shots. From the ten shots, the drive that generated the greatest CHV was taken forward for analysis (46).

Statistical analysis

Within-session reliability was determined using the coefficient of variation (CV) and intraclass correlation coefficient (ICC) statistics and their respective 95% confidence intervals. For each variable, acceptable reliability was determined as a CV <15% and an ICC >0.70 (18). The assumption of normal distribution for CMJ positive impulse, SJ positive impulse, DJ positive impulse, IMTP PF and CHV was met through visual assessment of histograms. The assumption of linearity and interval data were also met. Pearson correlation analysis was employed to measure the strength and direction of relationships between CHV and vGRF asymmetry for each of the protocols (CMJ, SJ, DJ and IMTP). IBM SPSS for Microsoft Windows (version 22.0; Chicago, USA), with an alpha level of $p \leq 0.05$ was used to assess statistical significance. It's important to recognise that asymmetries were converted to positive values for correlation analysis, however, Figures 1-4 indicate both the positive and negative values to represent the limbs these asymmetries favoured and to establish levels of agreement between limbs for different protocols. Given that the asymmetries may favour different legs between each of the test protocols, a Kappa coefficient was calculated to determine the level of agreement between asymmetries across two tests for each of the protocols employed (10). This was based on the premise that this statistic assesses the proportion of agreement between two tests once the agreement by chance has been removed (10). Kappa coefficients were determined as 'slight' (k = 0.01-0.20), 'fair' (k = 0.21-0.40), 'moderate' (k = 0.41-0.60), 'substantial' (k = 0.61-0.80) and almost perfect (k = 0.81-0.99) (44).

*****Tables 1-3 near here*****

RESULTS

Results from this study reveal that each of the protocols achieved acceptable levels of reliability (CVs <15%; ICCs >0.70), for the right and left leg (Table 1). Previous suggestions have been made that asymmetries should only be considered ‘real’ if the value is greater than the variability within the movement (14), which was represented by the CV statistic in the current study. Of the golfers tested, 26 had a ‘real’ asymmetry in the CMJ, 18 had a ‘real’ asymmetry in the SJ, 25 had a ‘real’ asymmetry in the DJ and 27 had a ‘real’ asymmetry in the IMTP. Descriptive statistics for the right leg and left leg along with the combined bilateral values are presented in Table 2. There was no significant relationship between CHV and asymmetry for CMJ positive impulse, SJ positive impulse, DJ positive impulse and IMTP PF (Table 3). The Kappa coefficient statistics indicated that the paired test results showed ‘slight’ levels of agreement on limb dominance between the CMJ and SJ (k = 0.12) and ‘slight’ agreement between the SJ and DJ (k = 0.06) but ‘fair’ agreement between the CMJ and DJ (k = 0.39). The reader is encouraged to pay particular attention to Figures 1-4, as these offer meaningful comparisons for individual golfers’ asymmetry and the limb these asymmetries favoured (positive = right, negative = left) during the four protocols.

*****Figures 1-4 near here*****

DISCUSSION

The aims of this investigation were to provide an asymmetry profile within golfers using a CMJ, SJ, DJ and IMTP and to assess the relationship these asymmetries had with CHV. Asymmetries can be reliably measured using these four protocols, however, no significant relationship was observed between asymmetries and highly skilled golfers CHV. Kappa coefficients indicate that asymmetries rarely favour the same limb, with Figures 1-4 indicating the varying nature of asymmetries for individual golfers between protocols. The combination of these results suggest that asymmetries are inherently individual and dependent on the task.

To date, this is the first investigation that has attempted to assess the relationship between asymmetry and CHV. The result of this investigation revealed that golfers who possess greater levels of asymmetry, are unlikely to benefit or suffer from higher or lower levels of CHV, respectively. Further research is needed to confirm whether addressing vGRF asymmetries leads to changes in CHV. Whilst these protocols present acceptable levels of reliability, the results indicate that not all golfers present a ‘real’ asymmetry. Therefore, it is important to measure asymmetries within golfers on an individual basis whilst considering their individual movement variability (8).

The levels of agreement between tests were poor based on the Kappa coefficient statistic, indicating that asymmetries rarely favoured the same side between protocols. Despite the homogenous sample investigated, the findings of the current investigation indicate that asymmetries are extremely varied for different golfers and are highly dependent on the task, which supports the findings of Bishop et al. (8). For example, golfer 34 achieved the lowest CHV (43.5 m/s) and presented a range of asymmetry magnitudes which were as follows, CMJ = 1.7% (Figure 1), SJ = 8.3% (Figure 2), DJ = 11.3% (Figure 3), IMTP = 14.7% (Figure 4). Additionally, golfer 47 achieved the highest CHV (55.6 m/s) and had a range of asymmetry magnitudes which were as follows, CMJ = 1.8% (Figure 1), SJ = 4.8% (Figure 2), DJ = 14.7% (Figure 3), IMTP = 2.4% (Figure 4). This inconsistency highlights the difficulty in assessing force production asymmetries, with several tests potentially required to establish these within golfers.

Bailey et al. (4) measured asymmetries in baseball and softball players, with results indicating asymmetries of 6.9% for IMTP PF. The golfers analysed in the current investigation presented greater asymmetry for IMTP PF (9.76%) when compared to those observed by Bailey et al. (4). In a separate investigation, Bailey et al. (3) noted that when compared to ‘stronger’ athletes, ‘weaker’ athletes demonstrated significantly greater levels asymmetry in the IMTP (9.41%), which are very similar to asymmetry values observed during the IMTP in the current study. This is interesting, since the subjects in the current study had limited resistance training which, conforms to Bailey et al's. (3) suggestion that absolute strength plays a significant role in influencing asymmetry. Indeed, Bazyler et al. (5) indicated that a 7-week resistance training programme significantly reduced asymmetries within 'weaker' athletes, emphasising the importance of improving overall strength. Resistance and plyometrics training have previously been found to significantly increase golfers CHV (12, 15), therefore, these training modalities should be considered as important component of a golfer's annual programme. Given that there were no significant relationships between CHV and vGRF asymmetries, training interventions could be specifically aimed at increasing CHV, which should lead to a competitive advantage on the golf course. Future research should endeavour to substantiate the effects that different forms of S&C interventions (i.e. resistance vs. plyometrics) have on addressing asymmetries in golfers' along with the effects these interventions have on performance.

It is important to recognise certain limitations within the current study. Firstly, whilst this study employed a homogenous sample, the results can only be generalised to highly skilled golfers. Furthermore, whilst there are inherent mechanical differences in the jumps, the specific force-time curve represents different 'phases' during the vertical jumps. For example, CMJ positive impulse comprises the braking phases and propulsive phase, whereas SJ positive impulse is representative of the propulsive phase, with DJ positive impulse inclusive of both muscular actions and body mass. Whilst there are differences in these 'phases', each of these protocols can reliably measure asymmetries within highly skilled golfers.

PRACTICAL APPLICATIONS

Practitioners can reliably use CMJs, SJs, DJs and IMTPs to examine asymmetries within highly skilled golfers. There were no significant relationships between CHV and asymmetries, and as such, vGRF asymmetries should be considered neither beneficial or detrimental to golfers' CHV. Further still, the results of this study indicate that asymmetries are inherently individual and task dependant. Based on the findings of this study and previous work (46), it would appear more beneficial to profile golfers using overall performance in these protocols, as opposed to relating asymmetries to CHV. Given that there is no relationship with between highly skilled golfers vGRF asymmetry and CHV, S&C coaches should implement interventions aimed at enhancing CHV. This is due to evidence of significant improvements in CHV following resistance training and plyometrics (12, 15), which should be considered important components of a golfer's annual programme.

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Disclosure statement

The authors report no conflict of interest.

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Table 1: The coefficient of variation and intraclass correlation coefficients along with their respective 95% confidence intervals for both the left and right leg for each of the protocols.

	Right Leg			**Left Leg**		
	Mean	95% CI Upper	95% CI Lower	Mean	95% CI Upper	95% CI Lower
CMJ Impulse CV%	4.84	5.71	3.98	5.25	5.98	4.53
CMJ Impulse ICC	0.96	0.97	0.93	0.97	0.98	0.95

SJ Impulse CV%	3.89	4.51	3.28	4.74	5.46	4.02
SJ Impulse ICC	0.97	0.98	0.95	0.98	0.99	0.96
DJ Impulse CV%	6.66	7.52	5.80	6.10	7.12	5.07
DJ Impulse ICC	0.95	0.97	0.92	0.94	0.97	0.90
IMTP PF CV%	6.32	7.41	5.22	7.56	8.80	6.32
IMTP PF ICC	0.96	0.98	0.92	0.97	0.98	0.94

N.B. CHV = clubhead velocity, CMJ = countermovement jump, SJ = squat jump, DJ = drop jump, IMTP = isometric mid-thigh pull, PF = peak force.

Table 2: Descriptive statistics for clubhead velocity and each protocol reflecting the right leg, left leg and combined bilateral values.

Variable	Mean	SD
CHV (m/s)	49.21	2.54
CMJ Bilateral impulse (N·s)	277.42	41.88
CMJ Right leg impulse (N·s)	143.63	25.19
CMJ Left leg impulse (N·s)	133.79	24.98
SJ Bilateral impulse (N·s)	184.33	27.82
SJ Right leg impulse (N·s)	93.78	14.39
SJ Left leg impulse (N·s)	90.55	14.65
DJ Bilateral impulse (N·s)	416.27	66.13
DJ Right leg impulse (N·s)	220.59	42.82
DJ Left leg impulse (N·s)	195.68	33.39
Bilateral IMTP PF (N)	1494.90	343.45
IMTP Right leg PF (N)	772.75	187.09
IMTP Left leg PF (N)	722.15	194.86

N.B. CHV = clubhead velocity, CMJ = countermovement jump, SJ = squat jump, DJ = drop jump, IMTP = isometric mid-thigh pull, PF = peak force.

Table 3: Descriptive statistics for asymmetry and their respective correlations with clubhead velocity.

Protocol	Mean	SD	*r* value
CMJ asymmetry (%)	8.21	5.91	-0.02
SJ asymmetry (%)	4.05	3.05	-0.14
DJ asymmetry (%)	8.11	7.15	0.22
IMTP asymmetry (%)	9.76	7.58	-0.05

N.B. CMJ = countermovement jump, SJ = squat jump, DJ = drop jump, IMTP = isometric mid-thigh pull.

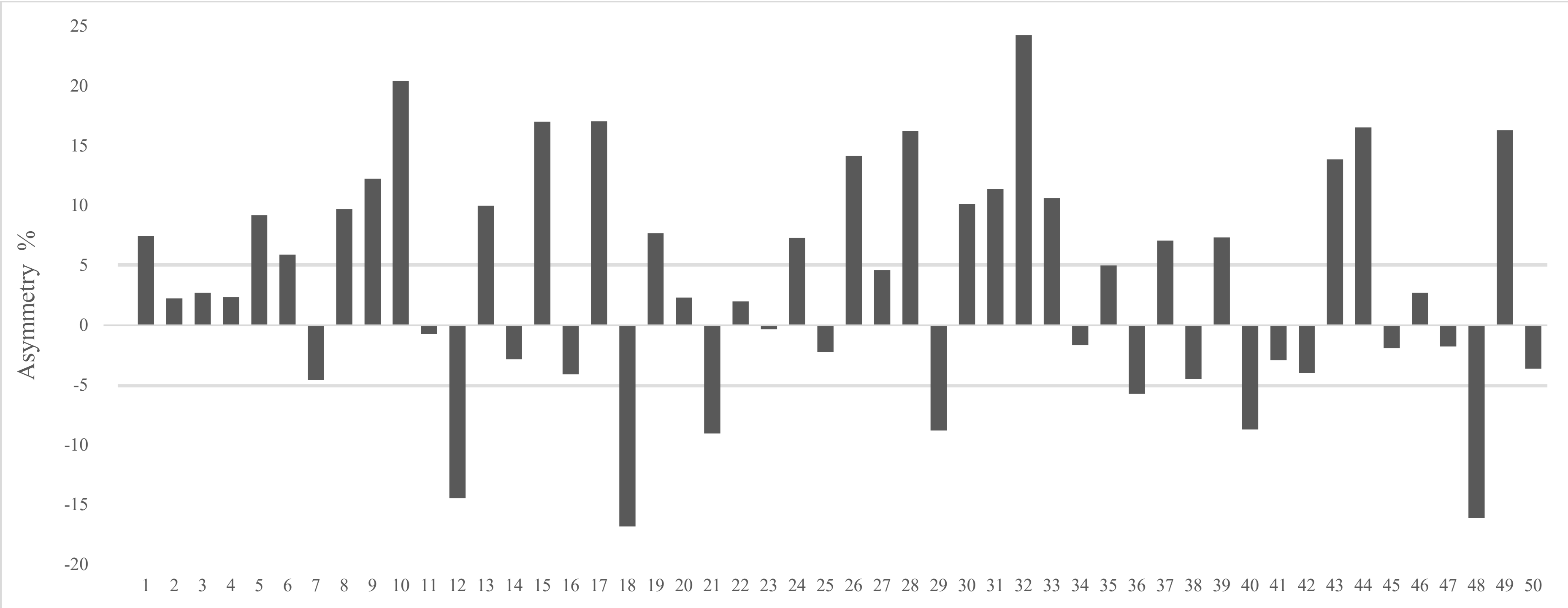

Figure 1: Individual positive impulse asymmetry values during the countermovement jump (CMJ). Above the 0 line indicates asymmetry favours the right leg and below the 0 line indicates asymmetry favours the left leg. Grey threshold line indicates a mean CV (when averaging values for both legs) of 5.05% for CMJ positive impulse.

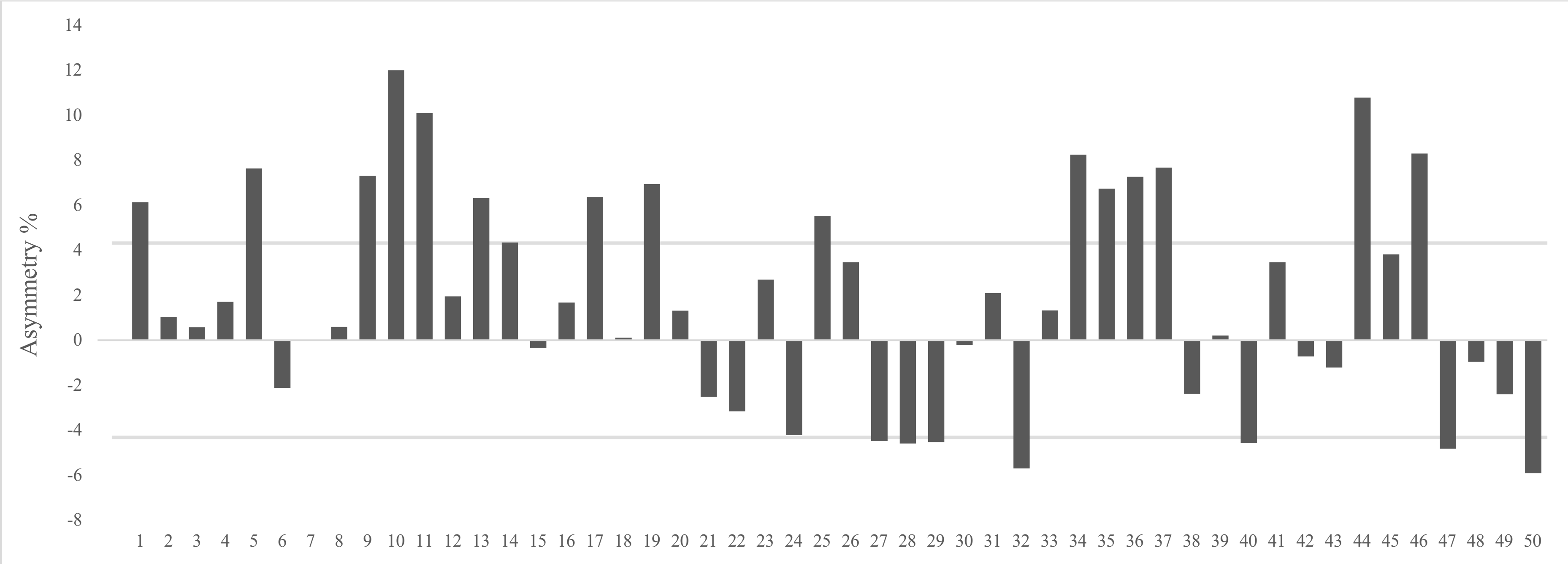

Figure 2: Individual positive impulse asymmetry values during the squat jump (SJ). Above the 0 line indicates asymmetry favours the right leg and below the 0 line indicates asymmetry favours the left leg. Grey threshold line indicates a mean CV (when averaging values for both legs) of 4.32% for SJ positive impulse.

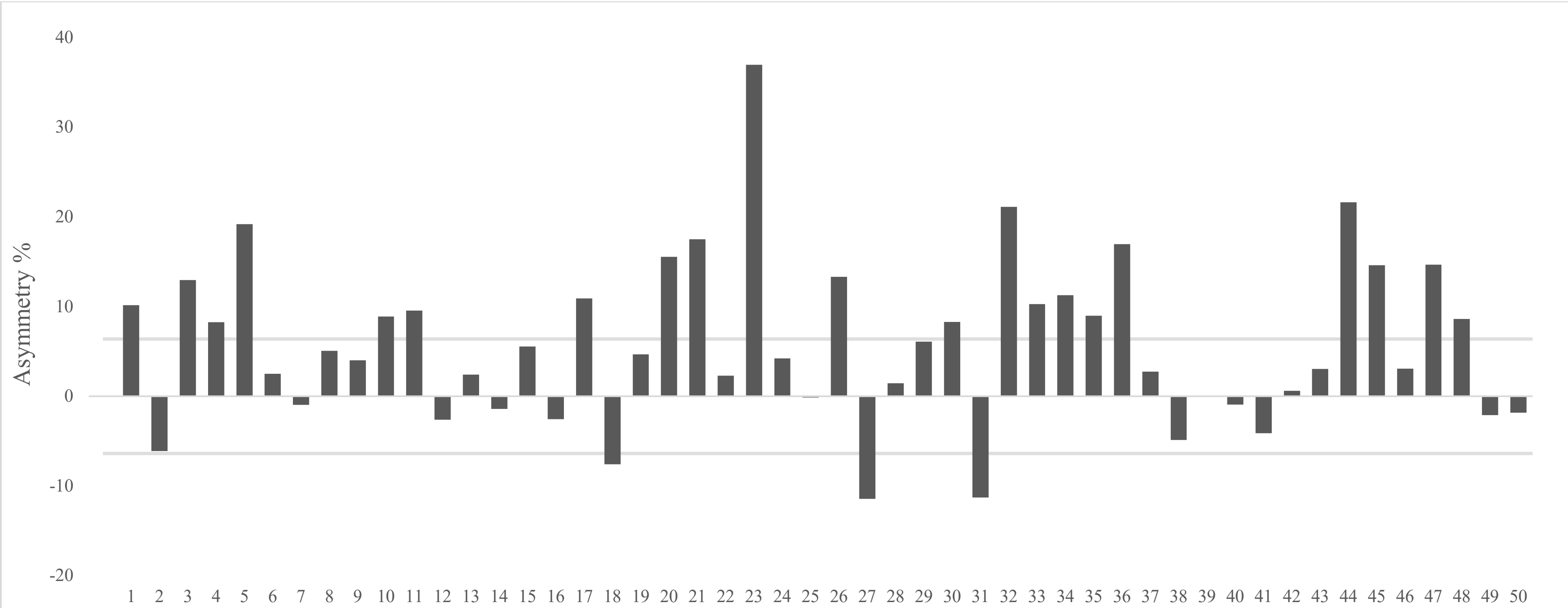

Figure 3: Individual positive impulse asymmetry values during the drop jump (DJ). Above the 0 line indicates asymmetry favours the right leg and below the 0 line indicates asymmetry favours the left leg. Grey threshold line indicates a mean CV (when averaging values for both legs) of 6.38% for DJ positive impulse.

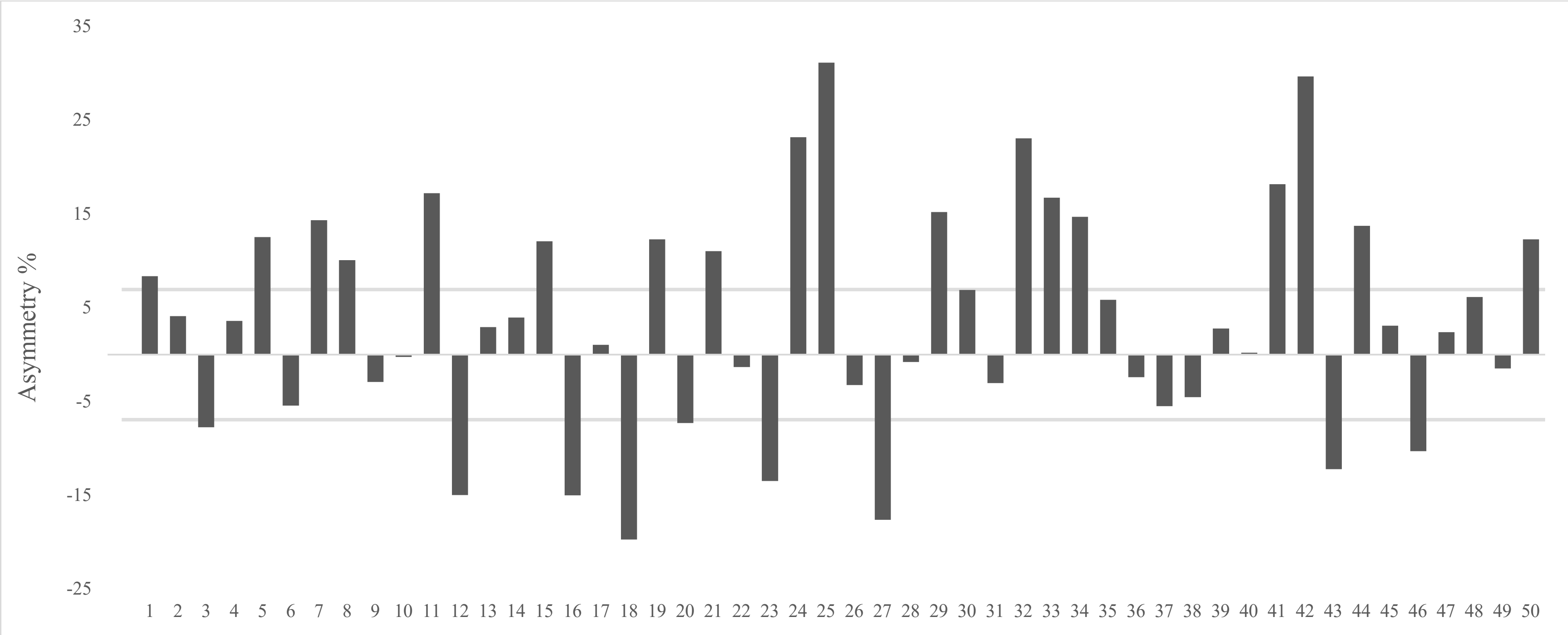

Figure 4: Individual peak force (PF) asymmetry values during the isometric mid-thigh pull (IMTP). Above the 0 line indicates asymmetry favours the right leg and below the 0 line indicates asymmetry favours the left leg. Grey threshold line indicates a mean CV (when averaging values for both legs) of 6.94% for IMTP PF.